Screw Driving Sounding Test for Soil Identification and Classification

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ABSTRACT: Screw Driving Sounding (SDS) test had been developed about a decade ago and has now been widely used in Japan together with the Swedish Weight Sounding (SWS) test in site investigation work, particularly for housing development project and investigating the performance levels of housing lots. Unlike SWS, studies in Japan and New Zealand show that the results from SDS tests can be used to identify and classify soil types and therefore it is able to give the soil profile without the needs of taking any soil samples. Recently this test has been introduced to researchers in Universiti Teknologi Malaysia to characterize various soil types. This paper discusses the results of the SDS tests in identifying and classifying various soil types in Malaysia. Test sites around Kuala Lumpur, Selangor and Johor had been chosen in performing the SDS tests. Results from three of the sites are compared with the borelogs obtained from the study area comprising of soil profile, Standard Penetration Test and laboratory tests results. Analysis shows that SDS is able to classify soil types in Malaysia besides its ability to identify soil layers in a more comprehensive manner. SDS data also correlates well with SPT-N values.
Keywords: Screw Driving Sounding, Standard Penetration Test, site investigation, soil profile, soil classification

1. INTRODUCTION

In Malaysia, deep boring with Standard Penetration Tests, SPT (with disturbed sampling) and undisturbed sampling for laboratory tests have been the common method for determining the subsurface soil profile and geotechnical engineering properties for foundation design purposes. SPT measures the resistance to penetration offered by soil at various depths (Wazoh and Mallo, 2014). SPT in Malaysia is carried out in accordance with MS1056:2005, using a hammer weight of 65 kg and a drop height of 750 mm. Total penetration is 450 mm and the number of blows for the last 300 mm is the SPT-N value.

Since performing deep boring either through wash boring, rotary drilling or percussion drilling are expensive, other tests such as Mackintosh or JKR probe is also carried out to complement the soil exploration work. In Japan, Swedish Weight Sounding, SWS has been widely used instead of Mackintosh or JKR probe. Recently, the Screw Driving Sounding, SDS test had been developed in Japan for value added to SWS. SDS is able to classify soil types as already proven for soils in Japan (Tanaka et al. 2012 and 2015, and Suemasa et al. 2018) as well as in New Zealand (Mirjafari, 2016 and Mirjafari et al. 2016). An attempt to implement the test in Malaysia has also been reported by Marto et al. (2018a) and (2018b).

A comparison made by Orense et al. (2013) between SDS and SWS, SPT as well as Cone Penetration Test, CPT indicated that SDS test has many advantages including simpler system, faster procedure, lighter reaction weight and better cost efficiency than other sounding tests. SDS also needs only small working area. Not just that, the data from the SDS machine could be sent to the 'cloud' and would be later downloaded from the G-web system for analysis. Once results are sent to the 'cloud', anyone with the given password could access to the analysed data. While the test crew is still at the site, one could instruct them to do more tests if upon checking through G-web system it shows questionable or contradictory results. This is the technology in line with the Industrial Revolution 4.0 that is by using automation in work and making use of the cloud computing technology (Marto et al., 2018a and 2018b).

2. SCREW DRIVING SOUNDING EQUIPMENT, TEST AND ANALYSIS METHODS

2.1 Equipment and Test Method

SDS equipment is shown in Figure 1 while the test method has been widely explained by previous researchers such as Tanaka *et al.* (2015), Mirjafari (2016), Mirjafari et al. (2016), Tanaka et al. (2016) and Marto et al. (2018b). Basically SDS test uses 7 number of load steps and the rod would penetrate the soil layer continuously at the rate of 25 rpm. The 7 load steps for SDS are 0.25, 0.38, 0.50, 0.63, 0.75, 0.88 and 1 kN. The load is increased for every revolution of the rod. For each 250 mm penetration, the rod will move up about 10 to 20 mm and rotate back down to calculate the rod friction.

(a) SDS equipment (b) Data can be sent to office through cloud system (c) Graphs of collected data can be viewed from mobile phone

Figure 1 Screw driving sounding test (https://www.j-shield.co.jp/english/sds.html)

Measurement items during SDS test includes torque of rod, applied load, penetration velocity and rotation speed at every revolution of the rod. Both load and torque are applied to the rod at the same time during the SDS test which is done automatically (Suemasa et al. 2018).

2.2 Theoretical Assumptions and Analysis Method

Suemasa *et al.* (2005) proposed a plasticity model for the SDS test from the results of SDS miniature tests. This plasticity model has been illustrated in Figure 2 by Tanaka *et al.* (2007). According to Tanaka et al. (2015), the combination of torque and vertical load measured in the SDS test forms a yield locus and the corresponding incremental components of a rotation rate and a settlement rate obey the plastic potential rule. The interactive relationship between the combined loads and the corresponding displacement of the soil element had been described as a constitutive equation.

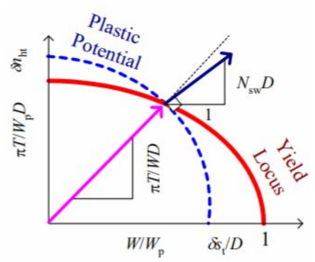


Figure 2 Concept of plasticity model for SDS (Tanaka *et. al.*, 2007)

SDS takes into consideration on rod friction during the test. The concept of estimating the rod friction has been explained by Tanaka et al. (2012) and shown in Figure 3. When the rod penetrates into the ground while being rotated during SDS test, two components of rod friction occurred, which are vertical component, Wf and horizontal component, Tf. The frictions are measured after each 250 mm penetration when the rod is lifted about 10 to 20 mm and then rotated back to the previous position. Through the Eq. (1) and Eq. (2) below, the corrected torque, T and corrected load, W at the screw point are calculated for each 250 mm penetration. It is necessary to deduct the friction to obtain the actual force applied to the rod.

$$W_a = W_f + W \quad (1)$$

$$T_a = T_f + T \quad (2)$$

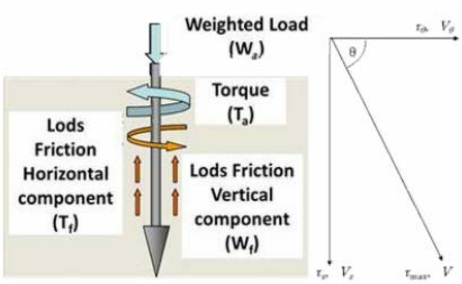


Figure 3 Concept of rod friction (Tanaka et al., 2016)

Through SDS data from 25 sites, the soils in Japan has been classified by Tanaka et. al (2015) in a so called " Soil Classification Chart" shown in Figure 4. The soil types are Clay, Silt, Sandy Clay, Loam and Peat. Similarly for soils in New Zealand, almost the same chart has been produced by Mirjafiri et al. (2016), as shown in Figure 5. The type of soils in New Zealand are Clay, Stiff Peat, Plastic Clay, Silty Clay, Clayey Silt, Sand, Sandy Silt, Silty Sand and Silt.

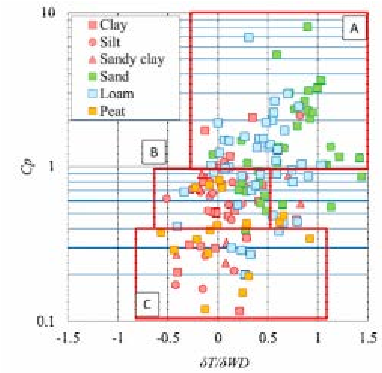


Figure 4 Soil Classification Chart for soils in Japan (Tanaka *et al*., 2015)

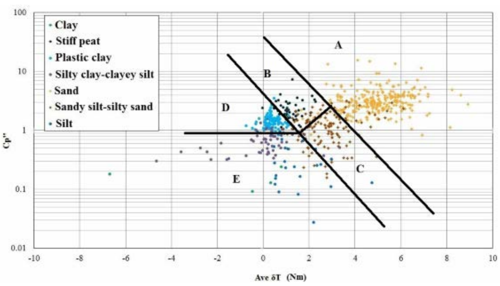


Figure 5 Soil Classification Chart for soils in New Zealand (Mirjafari *et al*., 2016)

The Soil Classification Chart is a plot of the coefficient of plastic potential, Cp' versus the slope of corrected torque divided by screw point diameter and corrected load, dT/dWD graph. Cp', which represents the difficulty of penetration, is obtained from approximate slope of the graph between the number of normalised half turns, $N_{SD}D$ and normalised torque ratio, πT/WD (Tanaka *et al.*, 2015). For New Zealand's Soil Classification Chart, it is the plot of Cp' against average change of torque, Ave (δT) with the equation as follows (Mirjafari, 2016):

$$Ave(\delta T) = \frac{1}{n-1}\sum_{i=1}^{n-1}(T_{i+1} - T_i) \quad (3)$$

where δT is the change in torque, T at each step of loading, i and n (=7) is the number of loading.

The chart developed by Tanaka *et al*. (2015) is divided into three areas; A, B and C based on the Cp' values of greater than 1.0 for sand and loam, between 0.4 to 1.0 for silt and clay, and below 0.4 for peat and organic soils. From SDS tests at 164 sites in Christchurch, Auckland and Wellington, New Zealand, Mirjafari et al. (2016) developed the Soil Classification Chart which is quite different with the Japan's chart. It is divided into five areas using four boundary lines to group the soil types; A is for sand, B for stiff peat, C for silty sand and sandy silt, D for stiff plastic clay and E for clayey silt, silty clay, clay and silt soils.

Some correlations between the data obtained from SDS tests had been carried out with SPT-N values by previous researchers in order to determine the relationship from both tests. This is necessary if SDS test is aimed at replacing SPT tests in the future because the design of shallow foundation in particular is generally using SPT-N value besides the strength parameters obtained from laboratory tests. Attempt on the correlation is through determining the relationship between the SPT-N value and the E0.25, the data acquired from SDS test. E0.25 is the penetration energy required for every 250 mm penetration of screw point (Tanaka et al., 2012). It has been reported by Tanaka et al. (2012) that the correlation between E0.25 and SPT-N value for Japan soils is as follows:

$$E_{0.25} = 0.268N_{SPT} \quad (4)$$

In New Zealand, the correlation between $E_{0.25}$ and SPT N value for sandy soil has been reported by Mirjafiri et al. (2016) as follows:

$$E_{0.25} = 0.34N_{SPT} \quad (5)$$

3. SDS FIELD TESTS

In the first attempt of using SDS in Malaysia, the SDS tests had been conducted at a total of 10 sites; four in around Kuala Lumpur and Selangor area and six in Johor area. The general soil types at the sites includes peat, residual soils, marine clay and sandy soils. In this paper only the test results from three sites are analysed and presented to represent preliminary results of the research.

Borehole records from deep boring using rotary drilling, comprising of soil profile, Standard Penetration Test as well as the sieve and Atterberg limit laboratory tests results are used to compare with SDS test data. These borehole records had been obtained from Public Works Department, PWD and the project owner. SDS tests were carried out close to the existing boreholes, which were within 1 to 2 m away in radius from the boreholes. Table 1 shows the site locations with respective SDS and Borehole number while Figure 6 shows the SDS test being carried out at one of the sites.

Table 1. Site Locations with Respective SDS and Borehole Number

No	Site location	SDS No.	Borehole	
			No.	Obtained from
1	Cheras	SDS28	BHJ1	PWD
2	Setapak	SDS37	BH2	PWD
3	Batu Pahat	SDS13	BH2	Project owner

Note: PWD – Public Works Department, Malaysia

Figure 6 Screw Driving Sounding test at Setapak site

3.1 Test Sites Location

Figure 7(a) shows the test site location around Kuala Lumpur and Selangor area while Figure 7(b) shows the sites around Johor area. The three sites in which results are presented in this papers are Cheras in Selangor, Setapak in Kuala Lumpur and Batu Pahat in Johor.

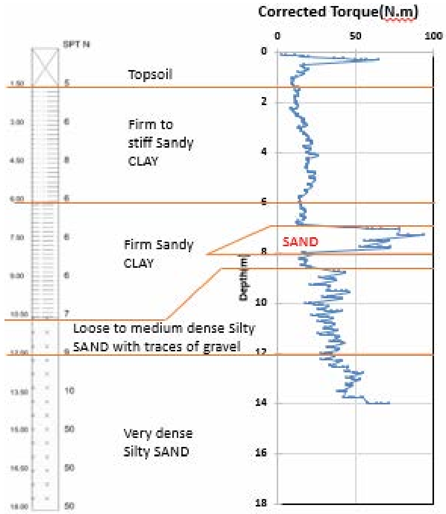
(a) Kuala Lumpur and Selangor area

(b) Johor area

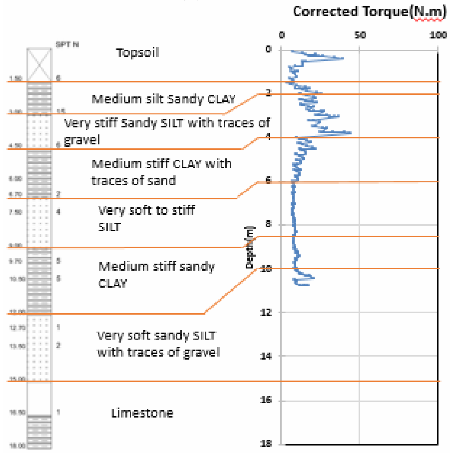
Figure 7 Test site locations

3.2 Soil Profile of Test Sites

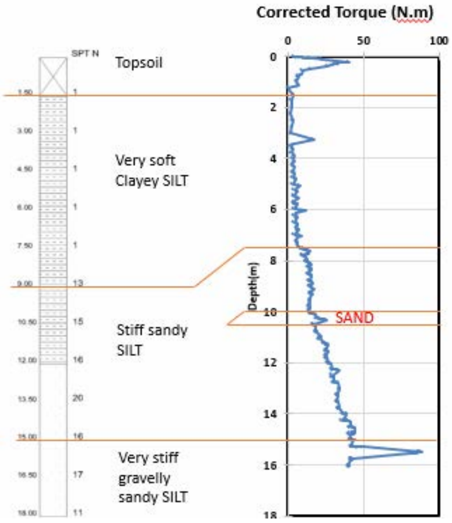
The soil profile from the nearby borelog and the plots of SPT-N value with depths as well as the SDS test results in terms of corrected torque are shown in Figure 8(a) for Cheras, Figure 8(b) for Setapak and Figure 8(c) for Batu Pahat area. Results from the borelogs are checked with the laboratory tests from the disturbed soil samples obtained through SPT tests. However, there is a disadvantage of soil profile plotted from borelogs such that the SPT-N values and soil laboratory results are obtained only every 1.5 m depth, unlike the SDS test which is a continuous result throughout the soil depth. In this case a more comprehensive results will be obtained from SDS tests.



(a) Cheras



(b) Setapak



(c) Batu Pahat

Figure 8 Soil profile at three selected sites from borehole record and screw driving sounding test

From borehole data, it can be seen that topsoil of 1.5 m thickness overlaid the soils at all sites. In Cheras the topsoil is underlain by 9 m of Sandy clay layer with SPT-N values ranges from 5 to 8 followed by silty SAND with traces of gravel between 10.5 m to 12 m depth and very dense Silty sand with SPT-N values between 10 and 50 below 10.5 m.

For Setapak, limestone is found at 15 m depth while the soil profile below topsoil are mixtures of sandy CLAY (1.5 to 3 m and 9 to 12 m depths), Sandy SILT (3 to 4.5 m and 12 to 15 m depths), stiff CLAY (4.5 to 6.7 m depth) and stiff SILT (6.7 to 9 m depth). The SPT-N values at Setapak site is very low except at 3 m depth (N=15), probably due to the existence of gravel within the Sandy SILT layer. Soil profile at Batu Pahat site generally consists of soft Clayey SILT up to 9 m depth with SPT-N value of 1, underlain by 6 m thick of stiff Sandy SILT and a very stiff gravelly sandy SILT thereafter. SPT-N values increased up to 20 below 7.5 m depth.

4. RESULTS AND DISCUSSION

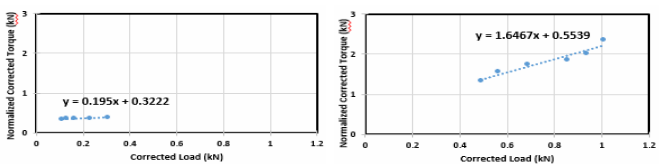
4.1 Identification of Soil Layer

Through SDS test, different layer and different types of soils are recognised from the range and pattern of corrected torque. Comparing the soil profile obtained from the borelog and SDS test, it seems that through SDS tests, the boundary of soil layers are mostly found earlier or shallower than the borelog. This is the advantage of SDS since the test is carried out continuously thus the boundary of each soil layers are detected more precisely.

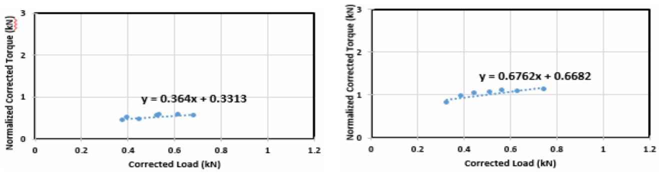
From the plot of corrected torque with depth, layers of soil such as sand can be detected. From Figs. 8(a) and 8(c), thin layers of sand are detected at Cheras site (from 6.75 to 8 m depth) and Batu Pahat site (from 10 to 10.5 m depth). Sand layers are identified through the shape of corrected torque developed at each 250 mm penetration. At this layer, the value of corrected torque increased with penetration depth at each seven steps load increment due to high friction as a result of the screw point going through the frictional soils. This phenomena, recognised in SDS test, has also been explained by Mirjafari et al. (2016). Since this is a very thin layer, investigation through deep boring using SPT was not able to identify its existence. On the other hand, torque is consistent with depths when SDS penetrates through clayey or silty soils due to none or limited frictional materials within the layer besides due to undrained situation resulted with zero friction angle. This can be seen as an example from 6 to 10 m depth at Setapak site.

4.2 Soil Classification

Previous studies on SDS data show that the data can be used to classify the soil type by determining the values of dT/dWD as well as Cp'. From the results of SDS test in Cheras, the graphs of normalised corrected torque, T/D versus corrected load, W at four selected 0.25 m section of penetration are shown in Figure 9. The slopes (dT/dWD) of the graphs are obtained from the equation of linear regression line shown in respective graphs. For stiff sandy clay in Figure 9(a) (depth between 1.75 m and 2.0 m) and firm sandy clay in Figure 9(c) (depth between 8.25 m and 8.5 m), the obtained slopes of 0.2 and 0.4, respectively are very small. Meanwhile for sand layer in Figure 9(b) (depth between 7 and 7.25 m, the slope is 1.7 and for silty sand in Figure 9(d) (depth between 9 to 9.25 m depth), the slope is nearly 1.



(a) 1.75 to 2.0 m (stiff sandy CLAY) (b) 7.0 to 7.25 m (SAND)

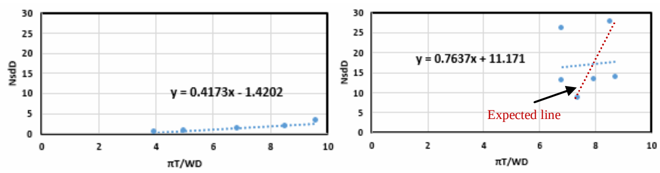


(c) 8.25 to 8.5 m (firm Sandy CLAY) (d) 9.0 to 9.25 m (Silty SAND)

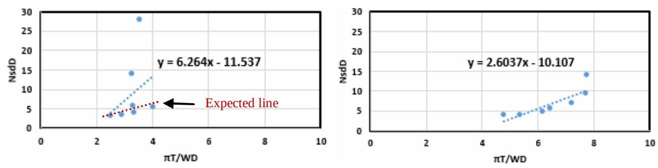
Figure 9 Relationship between normalised corrected torque and corrected load (at selected 0.25 m section) from Cheras Site

According to Tanaka et al. (2015), the slope of the plot between normalised corrected torque and corrected load tends to have a positive value for frictional soil like sand or loam, and negative value or zero for clay and silt. Also, through the plots of corrected torque versus corrected load, Tanaka et al. (2016) reported that the slope of the graphs shows positive value for sand or pumice while a negative or small value for silt or clay. The results obtained for the soil in Cheras are in agreement with what had been found by previous researchers using SDS test. As an example, for stiff clay, the normalised torque does not increase that much as the corrected load increases since the soil is fine-grained and frictionless under undrained condition. However for sand, the normalised torque increases as the corrected load increases. This is due to the resistance through the friction given by the coarse-grained materials of sand to the penetration of the SDS screw point.

Examples of Cp' obtained for Cheras site is shown in Figure10. A linear regression analysis from the plots of NSDD versus πT/WD identified the slope of the linear lines, also known as Cp'. For stiff sandy clay, the small value of Cp' obtained (0.4) is in line with the theory since the difficulty of penetration through cohesive soil is low. For silty sand with Cp' of 2.6, it is in agreement with the properties of frictional material, in which difficulty of penetration is shown by high Cp' value. However, the Cp' results for sand and firm sandy clay are incompatible with the soil types. By omitting some of the points, the expected lines to give the Cp' suitable to the soil types are shown in Figure 10(b) for sand and Figure 10(c) for firm sandy clay. The outliers probably transpired due to the 'noise' as a result of gravels that present within the soils.



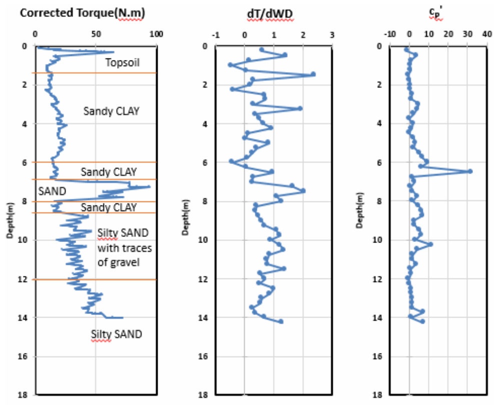
(a) 1.75 to 2.0 m (stiff Sandy CLAY) (b) 7.0 m to 7.25 m (SAND)



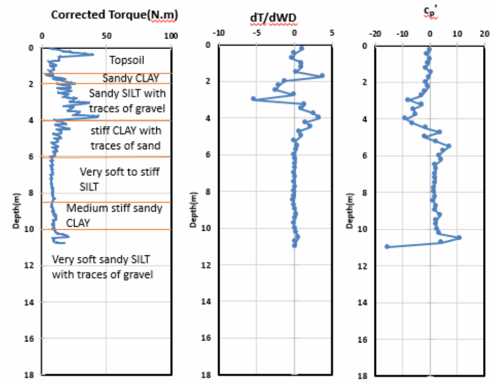
(c) 8.25 to 8.5 m (firm Sandy CLAY) (d) 9.0 to 9.25 m (Silty SAND)

Figure 10 Relationship between NSDD and πT/WD (at selected 0.25 m section) from Cheras Site

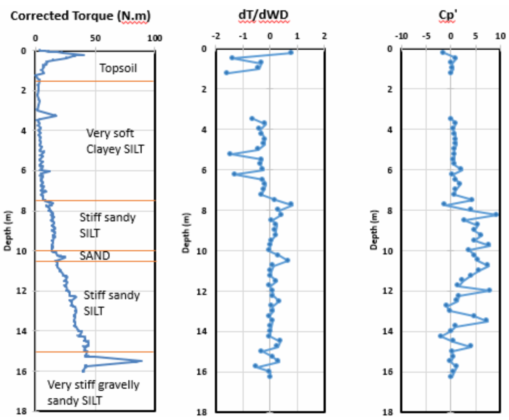
The variations of dT/dWD and Cp' for the soils with depth are shown in Figs.11(a), (b) and (c) for the sites of Cheras, Setapak and Batu Pahat, respectively. From these, the results for respective soil types are plotted in the Soil Classification Charts in which some are shown in Figure12. From the graphs in Figure12(a) and (b), it can be seen that generally the Silty SAND from Cheras occupied the right hand side of the chart with positive values of dT/dWD while for Cp', majority of the points spans from 0.9 to 7. For stiff Clayey SILT in Figure12(c), the points scattered on the left side of the chart with negative values of dT/dWD and Cp' of between 0.5 and 2.



(a) Cheras

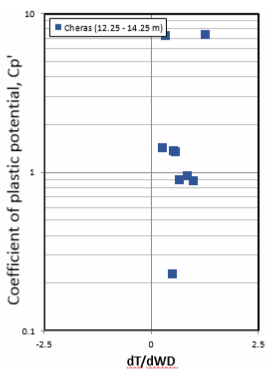


(b) Setapak

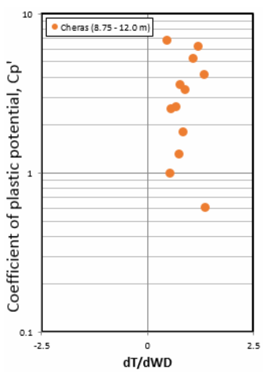


(c) Batu Pahat

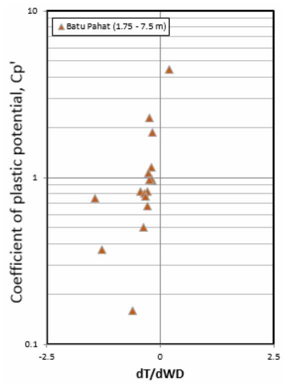
Figure 11 Variation of corrected torque, dT/dWD and coefficient of plastic potential with depths



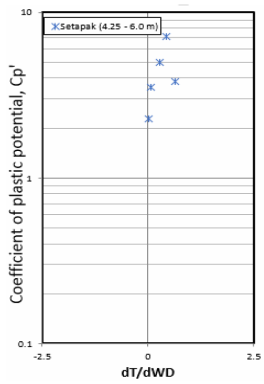
(a) Silty SAND



(b) Silty SAND with traces of gravel



(c) Clayey SILT



(d) Stiff CLAY

Figure 12 Relationship between coefficient of plastic potential, Cp' and dT/dWD for Silty SAND, Clayey SILT and Stiff CLAY

A preliminary Soil Classification Chart for soils in Malaysia based on the results from Cheras, Setapak and Batu Pahat is shown in Figure13. Although it has been developed from a very limited data, the trend for each soil types could be recognised. The most obvious one is for SANDY soils (silty sand, sandy silt and sandy clay) that occupied the top right hand side of the graph and also clayey SILT on the left hand side. This chart shows some similarity with soils in Japan and New Zealand.

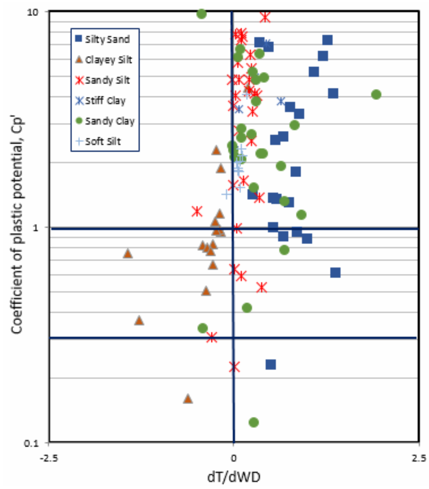


Figure 13 Preliminary Soil Classification Chart for soils in Malaysia

4.3 Correlation between SDS and SPT Test

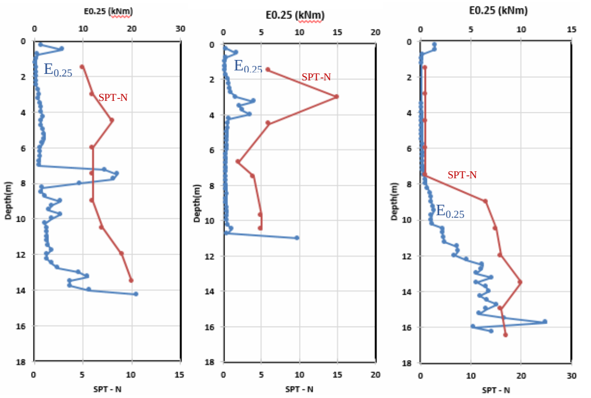
Data from SDS tests are correlated with SPT-N values obtained from nearby borehole record. Figure 14 shows a comparison between $E_{0.25}$ and SPT-N values with depth for all sites. In general the trend between $E_{0.25}$ and SPT-N values with depth is similar for all sites

Figure 15 shows the plots of $E_{0.25}$ with SPT-N or N_{SPT} values.Based on the statistical analysis using linear regression method, it is found that the coefficient of determination, R^2 for the correlation between SPT-N value and $E_{0.25}$ are all above 0.71 (coefficient of correlation, R greater than 0.842) which shows more than 71% of $E_{0.25}$ is dependent on SPT-N. Hence this is considered as a very good correlation since SDS test result ($E_{0.25}$) is highly correlated with SPT-N values despite the limited data obtained. Below are the summary of correlation equations between SDS data and SPT-N values:

Cheras, $E_{0.25} = 0.2N_{SPT}$ (6)

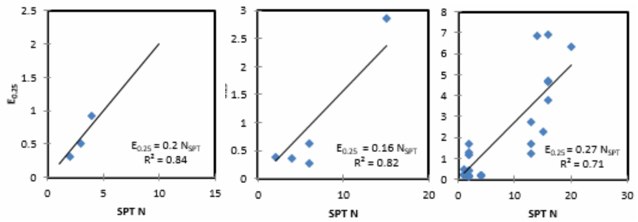
Setapak, $E_{0.25} = 0.16N_{SPT}$ (7)

Batu Pahat, $E_{0.25} = 0.27N_{SPT}$ (8)



(a) Cheras (b) Setapak (c) Batu Pahat

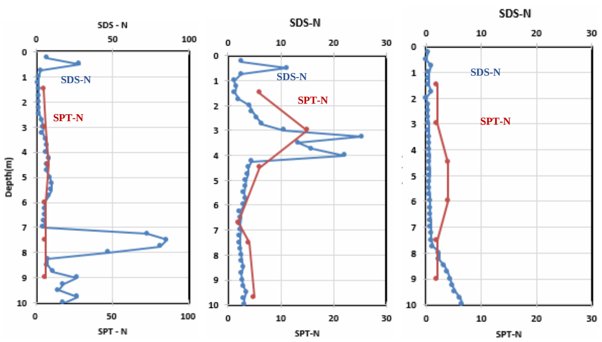
Figure 14. Comparison between $E_{0.25}$ and SPT-N values with depth



(a) Cheras (b) Setapak (c) Batu Pahat

Figure 15. Correlation between total energy required for 0.25 m penetration ($E_{0.25}$) with SPT-N value (NSPT)

Comparing the results obtained by soils in Japan (Tanaka et al., 2016) shown in Eq. (4) and New Zealand, (Mirjafari, 2016) shown in Eq. (5), it seems that the results are comparable. From the results obtained, the variation of SPT-N with depth is compared through the plots in Figure 16 for all the three sites. The variation is in agreement except for the site in Cheras. Beyond 7 m depth the SPT-N values seem to be consistent while for SDS-N, it increases with depth. The results of SDS is in line with the type of soil which is firm Sandy CLAY followed by dense Silty SAND as shown earlier in Figure 8(a). Logically, the N value will increase with depth in this type of soils as resistance to the hammer penetration increases.



(a) Cheras (b) Setapak (c) Batu Pahat

Figure 16. Comparison between SPT-N value and estimated SDS-N value throughout soil depths

5. CONCLUSION

Screw Driving Sounding Tests, SDS had been performed successfully at various sites in Selangor, Kuala Lumpur and Johor area. The results analysed from three sites indicate that SDS data have a very good correlation with SPT-N values. SDS data are also capable to be used in identifying and classifying different type of soils. Through the development of a preliminary Soil Classification Chart, Sandy Clay, Sandy Silt, Clayey Silt, Silty Sand, Stiff Clay and Soft Silt, found from Cheras, Setapak and Batu Pahat sites could be identified. However, for developing the chart that will represents validly the soils in Malaysia, it is necessary to have more SDS test data. This is also required to develop a valid correlations between SDS data and SPT-N value. Hence, the current research will be extended to other test sites throughout Malaysia in the near future.

6. ACKNOWLEDGEMENT

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